Single field-of-view cloudy sounding retrieval from hyperspectral IR radiances

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(and many NASA/NOAA/UW colleagues)

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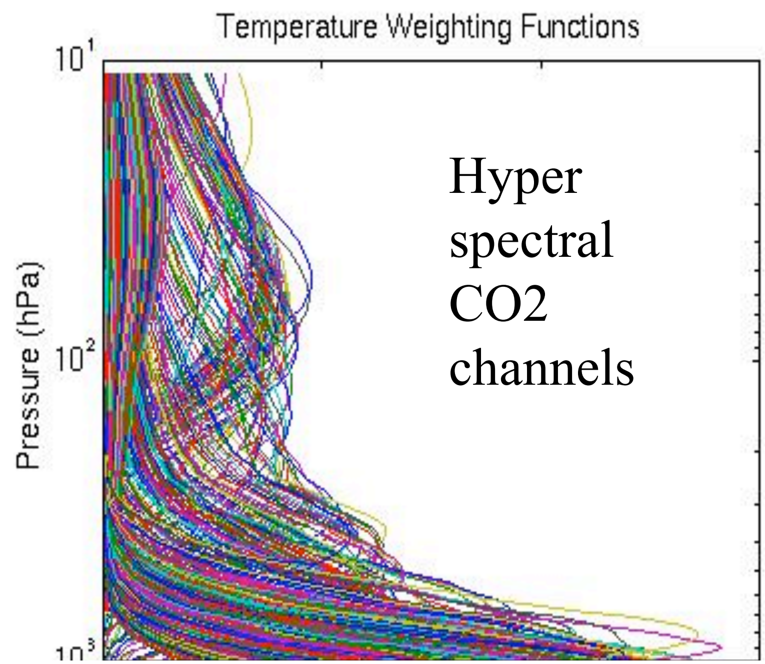
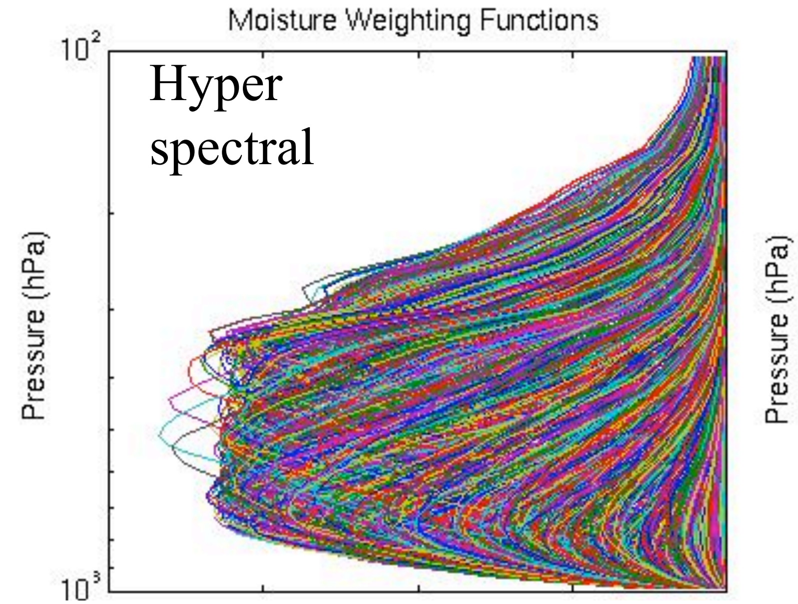
Acknowledgement

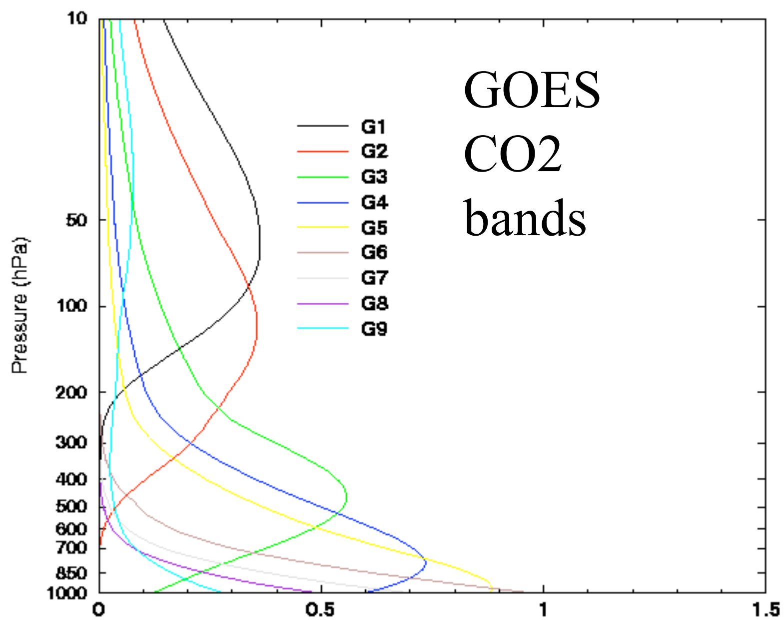
- Dr. Jinling Li for emissivity work
- Dr. Elisabeth Weisz for cloudy sounding work

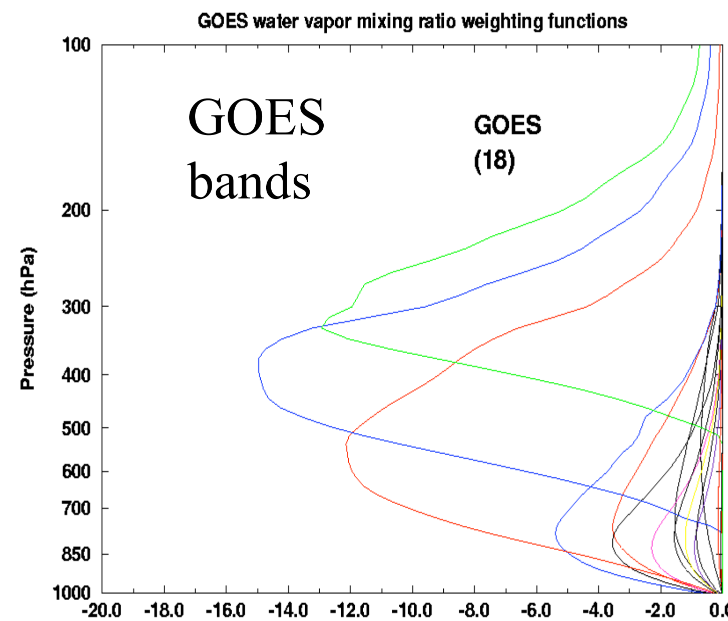
Why IR alone sounding is useful?

- IR alone moisture soundings preserve spatial gradients that are important for monitoring/predicting mesoscale features,
- Other meteorological applications (short-range forecast and now cast, mountain wave etc.)


Temperature Weighting Functions
Pressure (hPa)
Hyper
spectral
CO2
channels


Moisture Weighting Functions
Pressure (hPa)
Hyper
spectral
Pressure (hPa)


Pressure (hPa)
G1
G2
G3
G4
G5
G6
G7
G8
G9
GOES
CO2
bands


GOES water vapor mixing ratio weighting functions
Pressure (hPa)
GOES
bands
GOES
(18)

Hyperspectral IR alone sounding

- Algorithm description
- Handling surface IR emissivities
- Handling clouds
- NASTI demonstration
- AIRS verification
- Summary

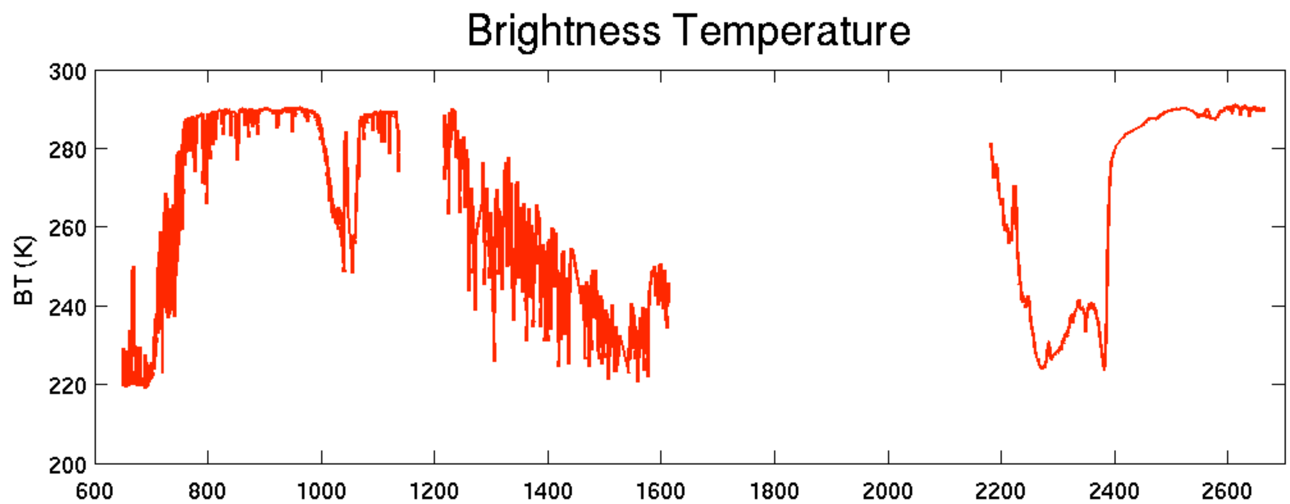
Hyperspectral SFOV clear/cloudy sounding retrieval

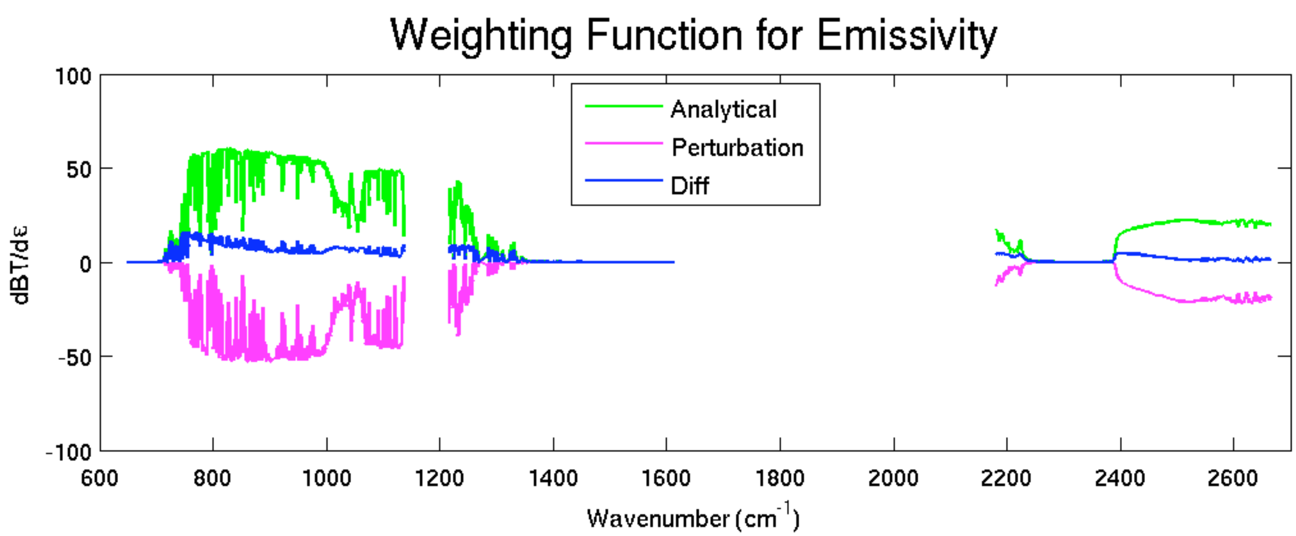
- Clear sounding retrieval
  - Clear Regression
    - Global training with realistic surface IR emissivities
  - Regularization (physical iterative approach)
    - Use regression as first guess, retrieval of sounding and emissivity spectrum
- Cloudy Sounding retrieval
  - Cloudy regression
    - Realistic cloud radiative transfer model
    - Cloudy training data set
  - Regularization (physical iterative approach)
    - Use regression as first guess, retrieval of sounding and cloudy properties

Handling surface IR emissivity

- Emissivity spectrum is expressed by its eigenvectors (derived from laboratory measurements)
- Regression retrieval are used as the first guess
- Simultaneous retrieval of emissivity spectrum and soundings in physical iterative approach

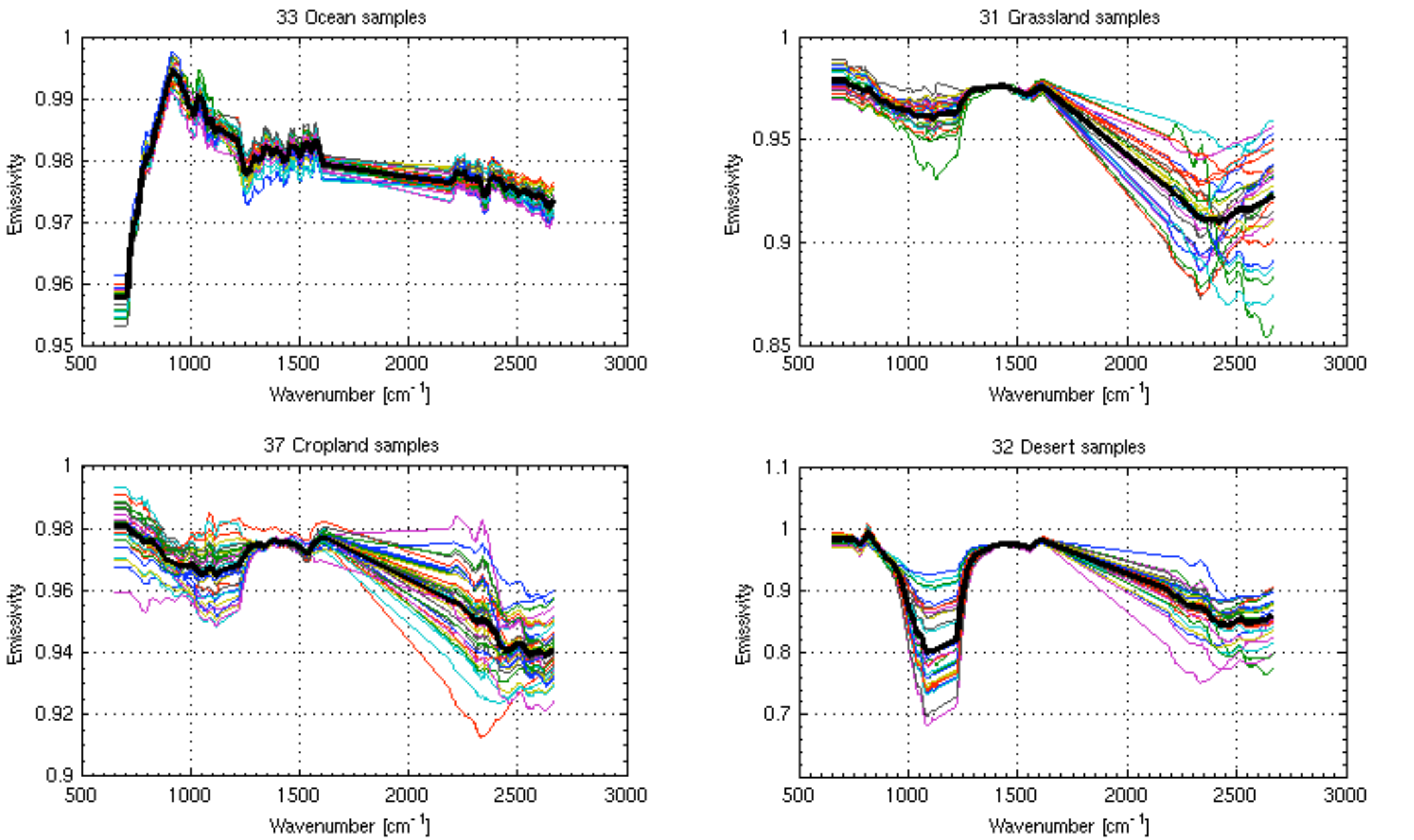
Weighting Function for Surface Emissivity (AIRS)



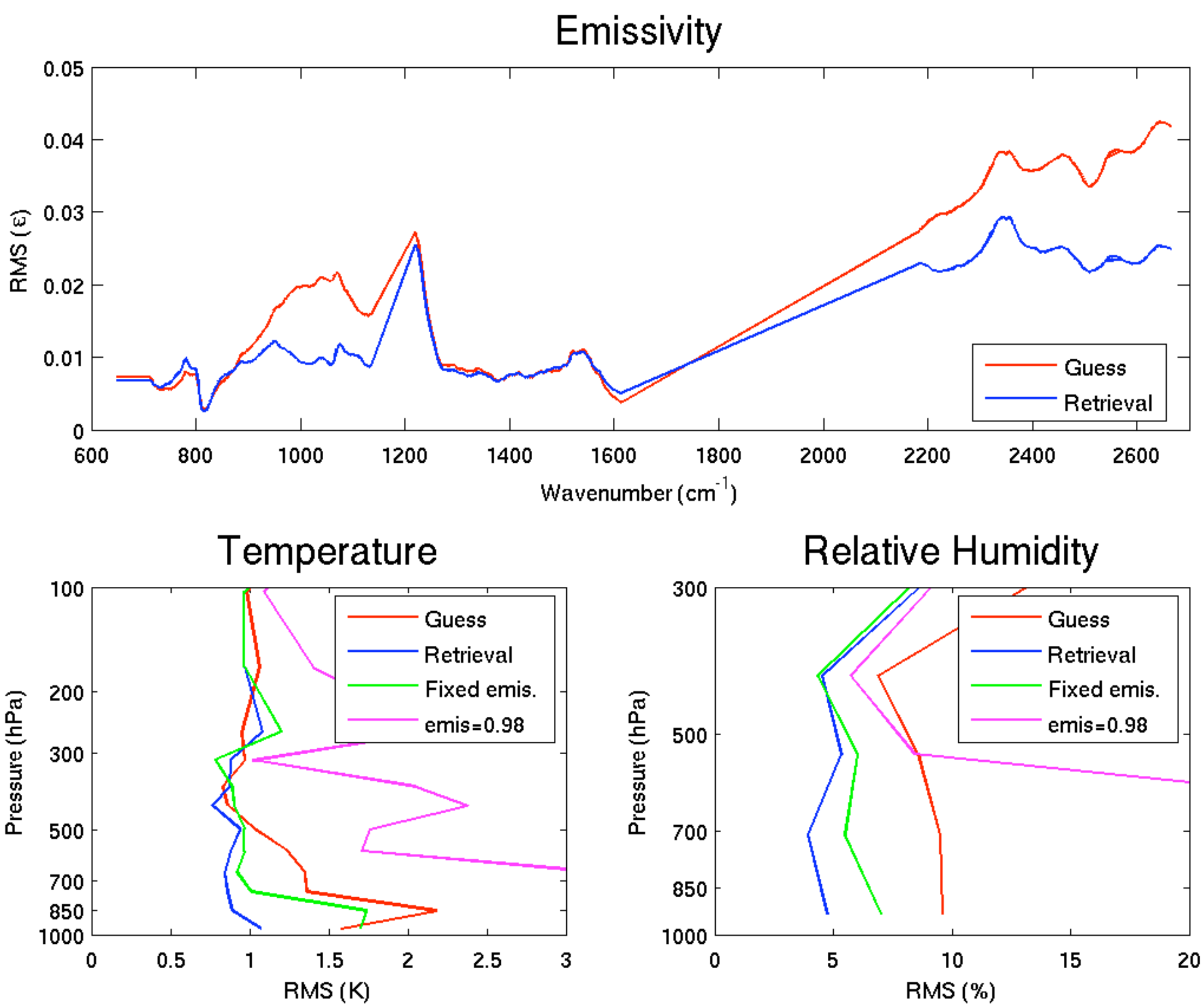


Unlike microwave sounder, emissivity signal in IR is small (e.g., 0.01 emissivity results in ~0.5 K change in window region), but its impact on boundary sounding is significant.

Emissivity Spectrum Assignment to Training Profiles



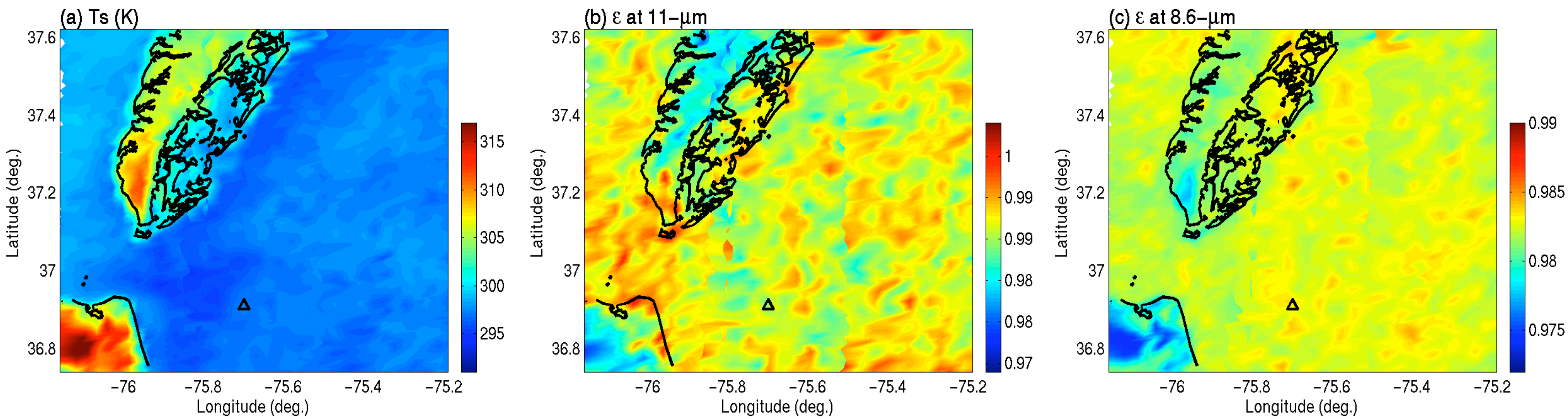
Simulated Retrieval for Desert (32 profiles)



Tskin RMS (K)	
Reg	0.624
Rtv	0.540
Fixed emis	0.822
Emis= 0.98	9.544

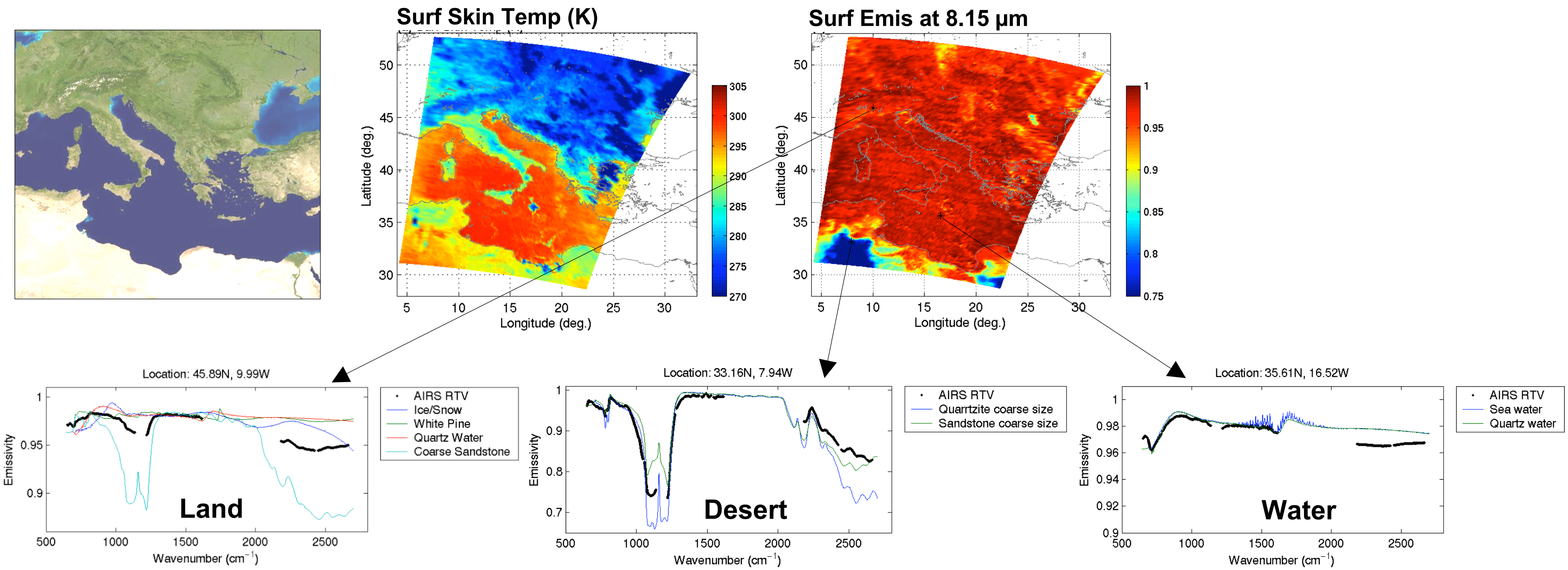
Surface Emissivity Retrieved with NAST-I

Retrievals of (a) surface skin temperature, (b) surface emissivity at 11-μm, and (c) surface emissivity at 8.6-μm from NAST-I observations on <u>14 July 2001</u>. The Chesapeake Lighthouse site is shown by the open triangle.



Surface Emissivity Retrieved with AIRS

Accurate surface properties captured by hyperspectral measurements featured over the land, especially in the vicinity of the Sahara Desert, are clearly evident.



Handling clouds

- Cloudy training data set is generated with cloud-top pressure, optical thickness, particle radius assigned
- Fast cloudy radiative transfer model is derived from coupling clear sky transmittance model (SARTA) and single scattering cloud model
- Retrieval is derived from regression, can be enhanced by physical approach (Zhou et al. 2007).

Fast cloudy radiative transfer model

- Developed in collaboration with Texas A&M University (H. Wei, P. Yang)
- Cloudy radiances can be computed from coupled clear-sky optical thickness (computed by SARTA) and cloud single-scattering properties.

$$R = R_o F_T \tau_c + (1 - F_T - F_R)\, B_c \tau_c - \int_0^{pc} B\, d\tau + F_R\, \tau_c \int_0^{pc} B_c\, d\tau^*$$

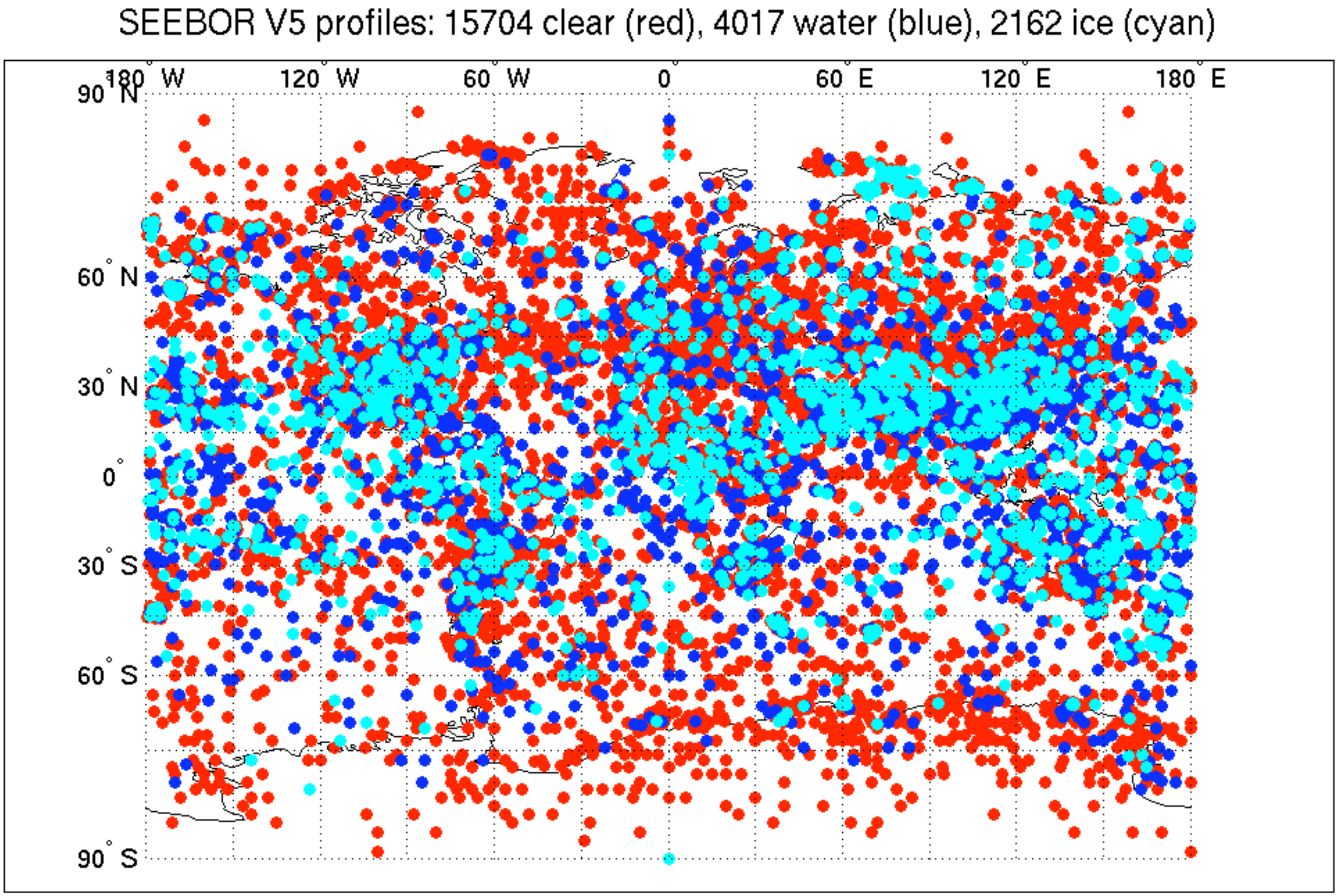
R_0…radiance below cloud (=R_s+$R\uparrow$+$R\downarrow$), B…Planck function, pc …cloud top pressure,

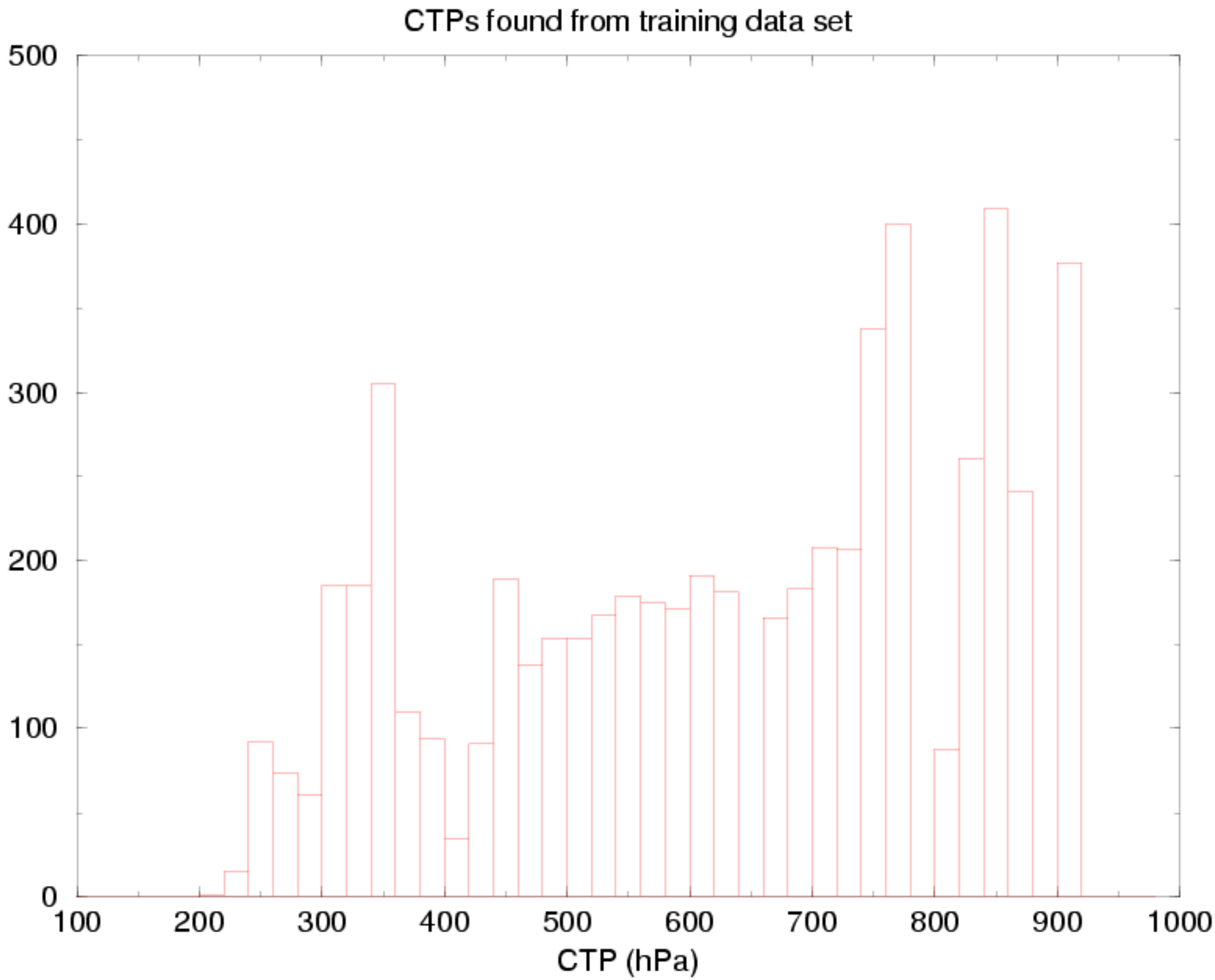
τ_c…transmittance of cloud top, $\tau^* = \tau_c^2/\tau$ … downwelling transmittance,

F_R…cloud reflectance function, F_T…cloud transmissive function

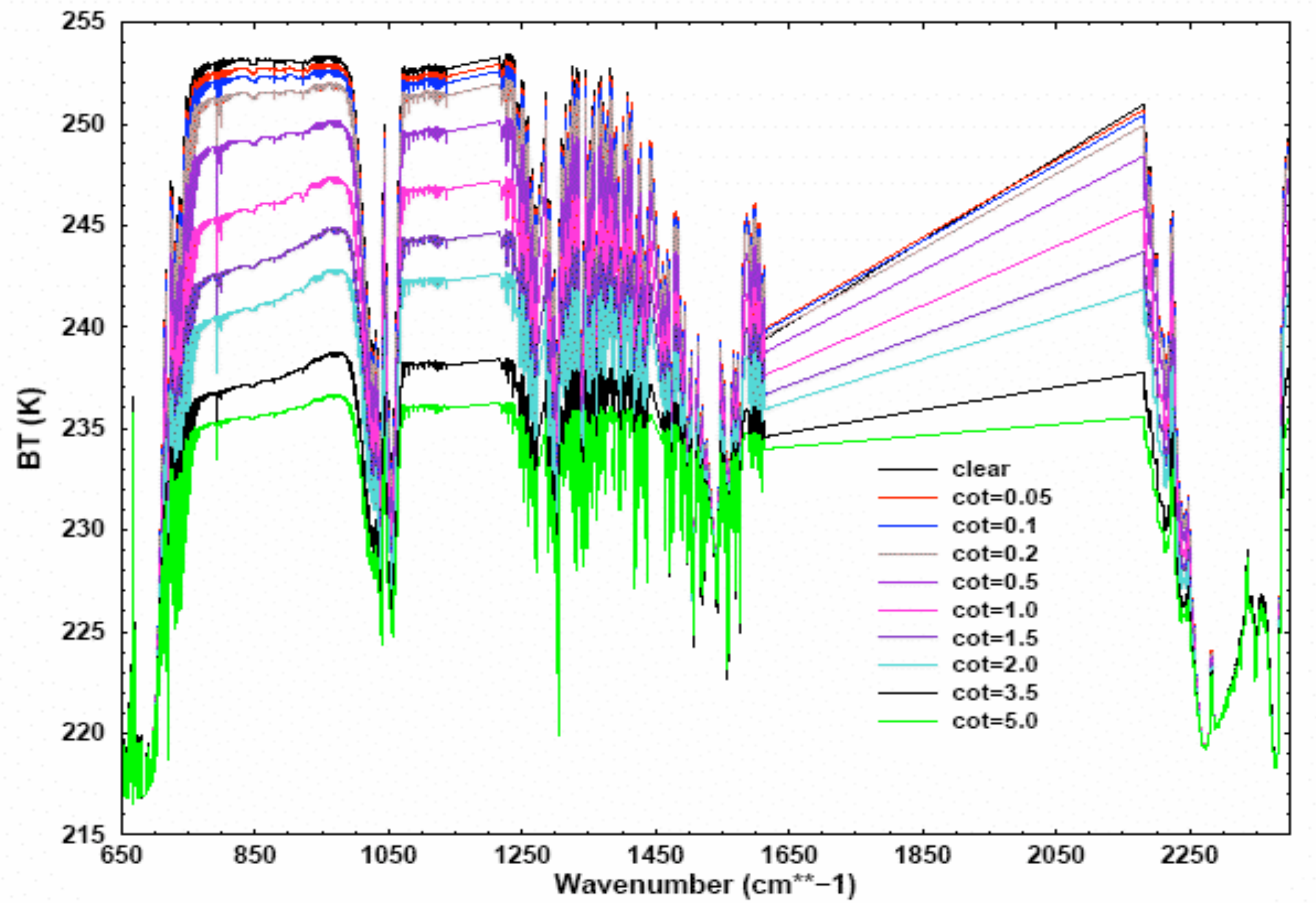
- Reflectance (albedo) and transmissive functions for various CPS (Cloud Particle Size) and COT can be obtained from a pre-described parameterization of the bulk single-scattering properties of ice and water clouds
- Ice clouds: assumption of aggregates, hexagonal geometries and droxtals for large (>300 μm), moderate (50 - 300 μm) and small particles (0-50 μm) respectively.
- Water clouds: assumption of spherical droplets and application of classical Lorenz-Mie theory.

From 15704 profiles, profiles 4017 profiles are water clouds and 2162 are ice clouds




CTPs found from training data set
500
400
300
200
100
0
100
200
300
400
500
600
700
800
900
1000
CTP (hPa)

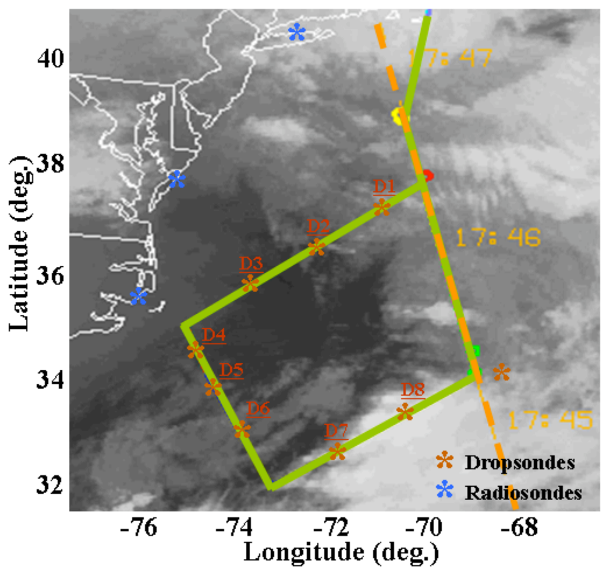
AIRS BT spectrum



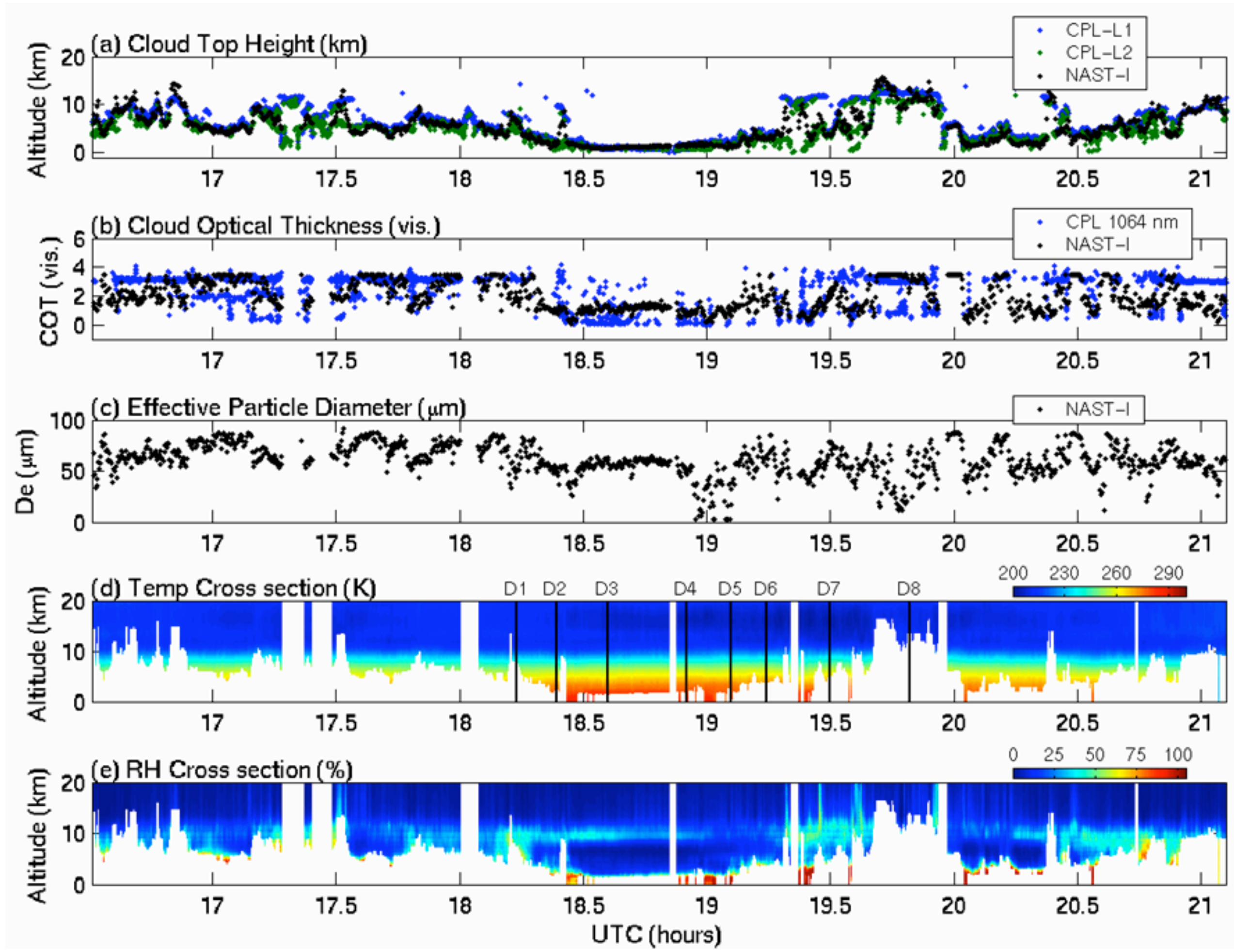
Whole sounding in broken clouds and above-cloud sounding in thick clouds can be derived

Cloudy sounding retrieval – NASTI demonstration

Cloud properties captured by NAST-I hyperspectral measurements. Sounding accuracies close to those achieved in totally cloud-free conditions are achieved down to cloud top level.

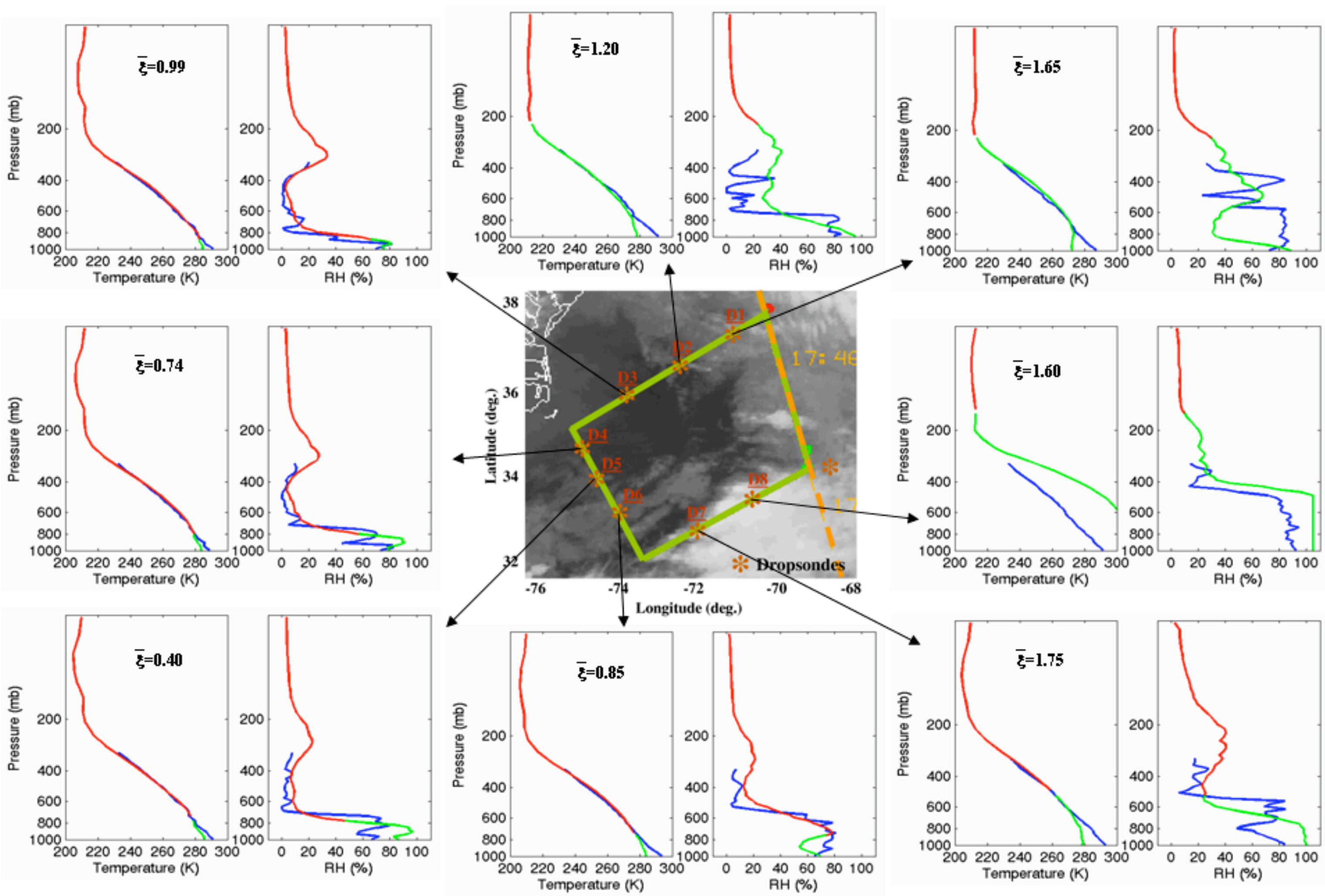


GOES-8 infrared image (at 18:30 Z) shows a variety of clouded conditions; such as medium-level altocumulus, low-level cumulus, thunderstorms, and extensive high cirrus in the region covered by the ER-2 and the G-4. The ER-2 flight track is plotted over the GOES image



Cloudy sounding retrieval – NASTI validation

Accurate soundings to the cloud top are captured and comparable to clear sounding retrievals.

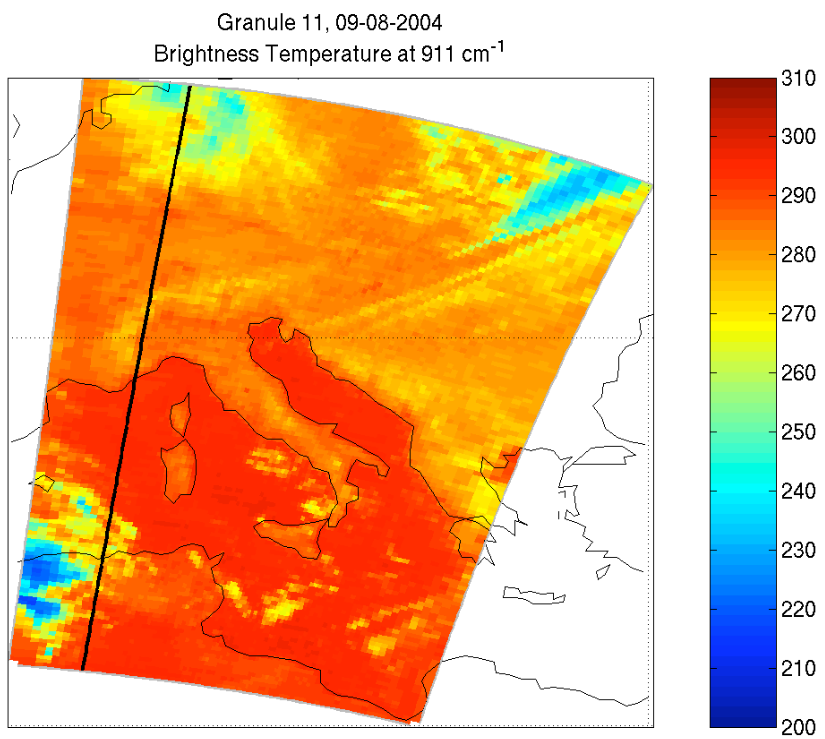


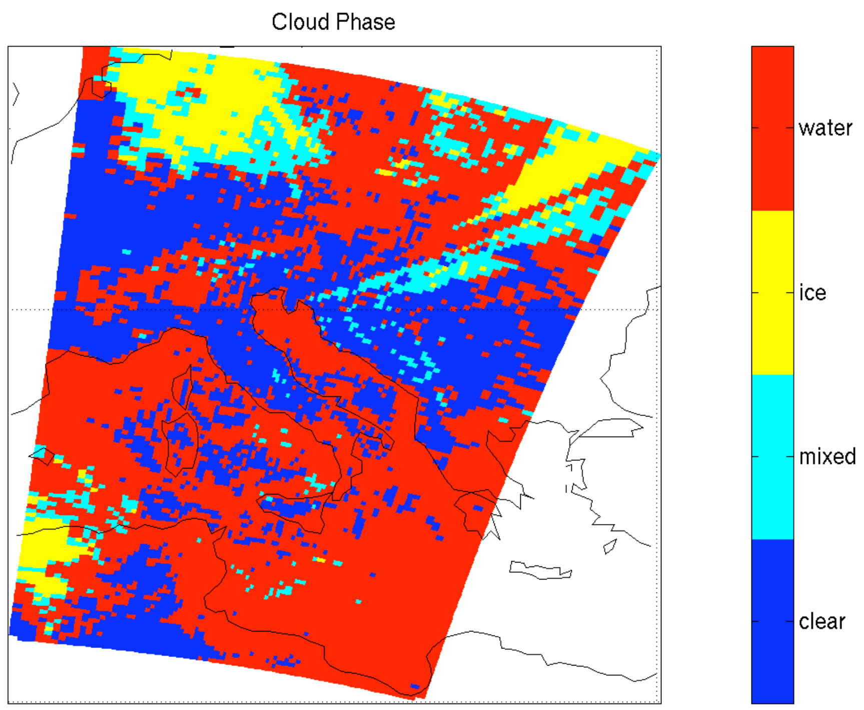
Red curves: retrievals above the cloud.

Green curves: retrievals below the cloud.

Blue curves: dropsondes.

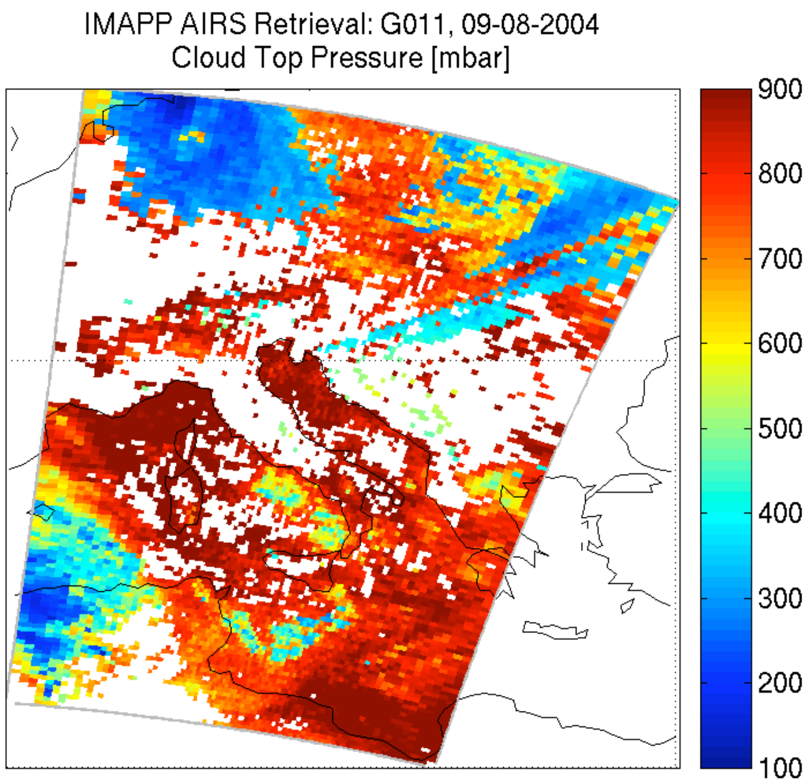
Granule 11, 09-08-2004
BT at 11 micron and Cloud Phase
(IR cloud phase detection technique is used)





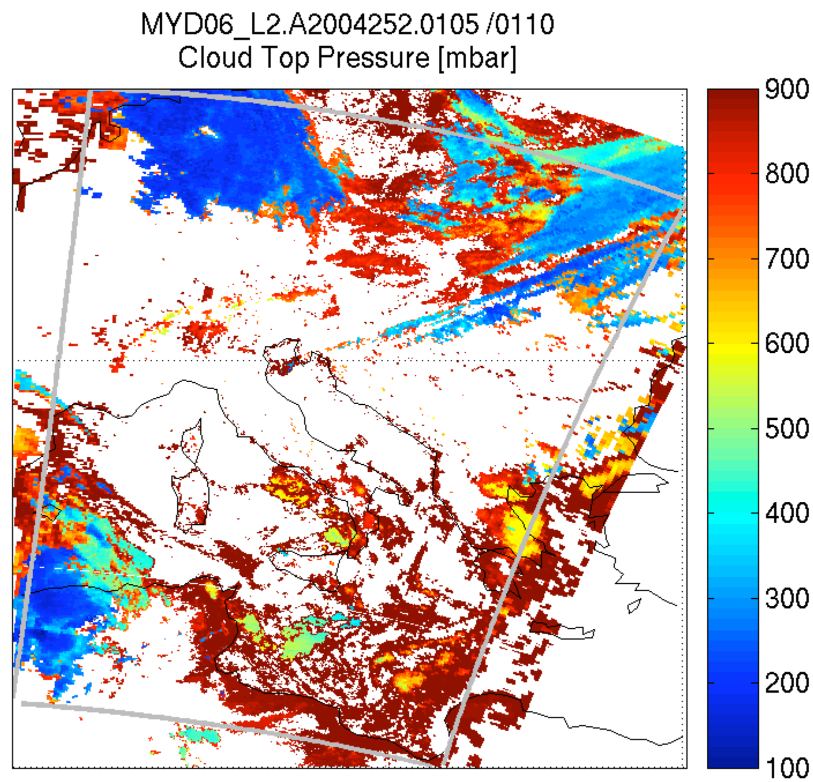
Retrieved Cloud Top Pressure

AIRS RTV



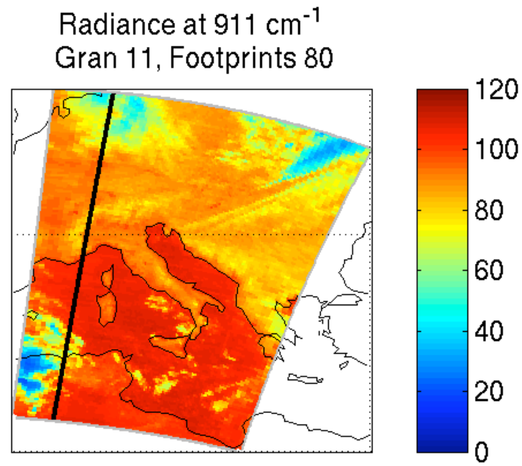
AIRS SFOV CTP is simultaneously retrieved with temperature and moisture soundings

MODIS RTV

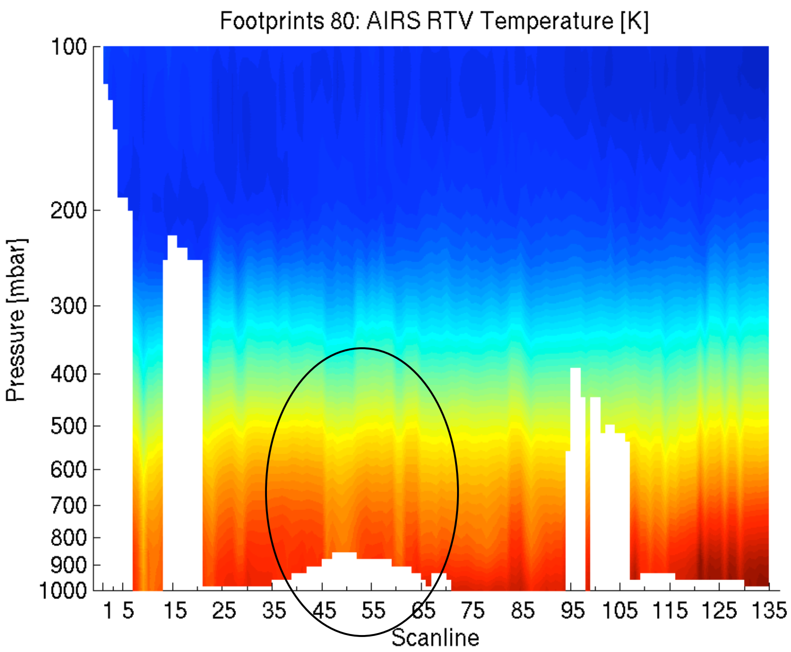


Operational MODIS CTP is derived with GDAS forecast profile

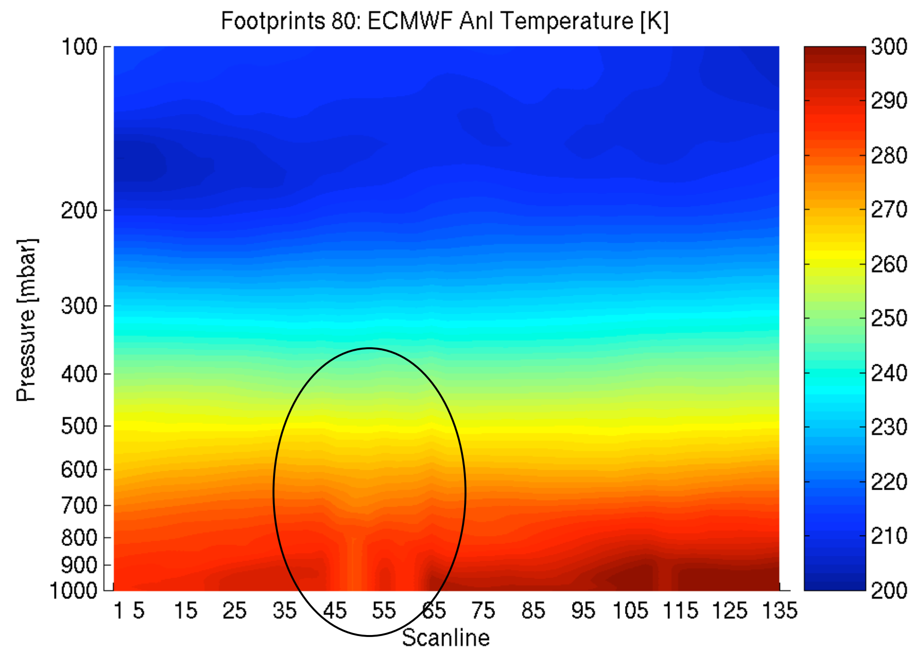
Retrieved Temperature along Footprints 80



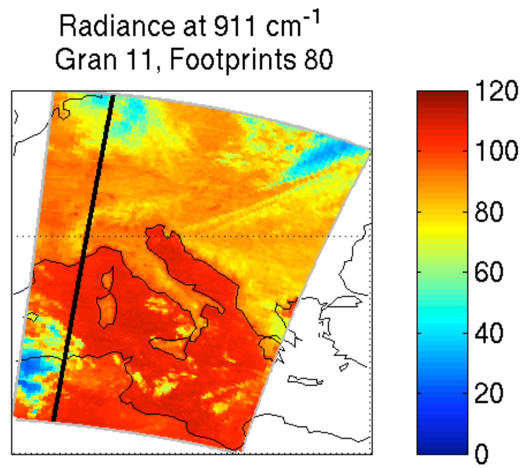
Cloudy RTV



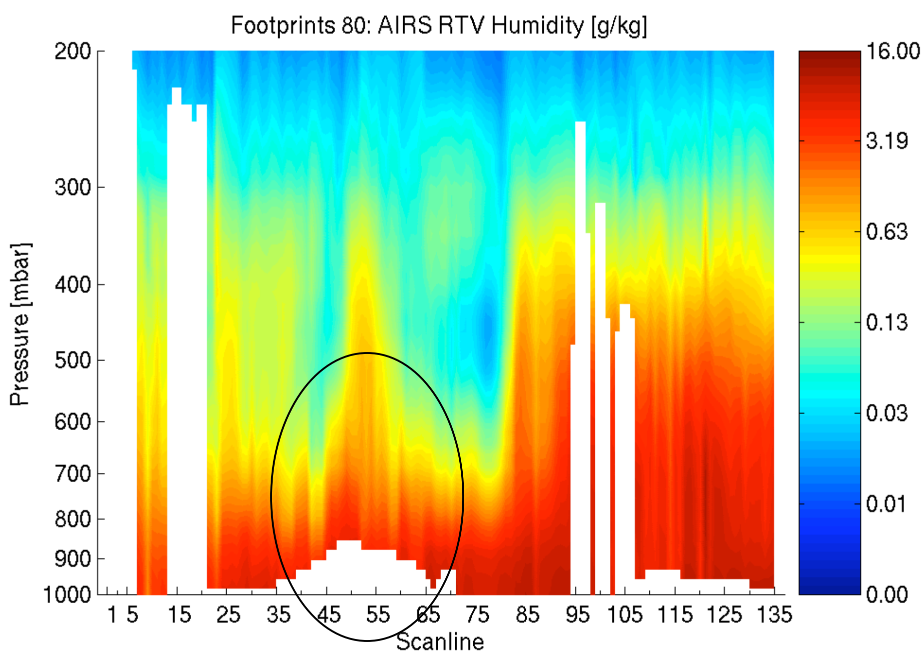
ECMWF



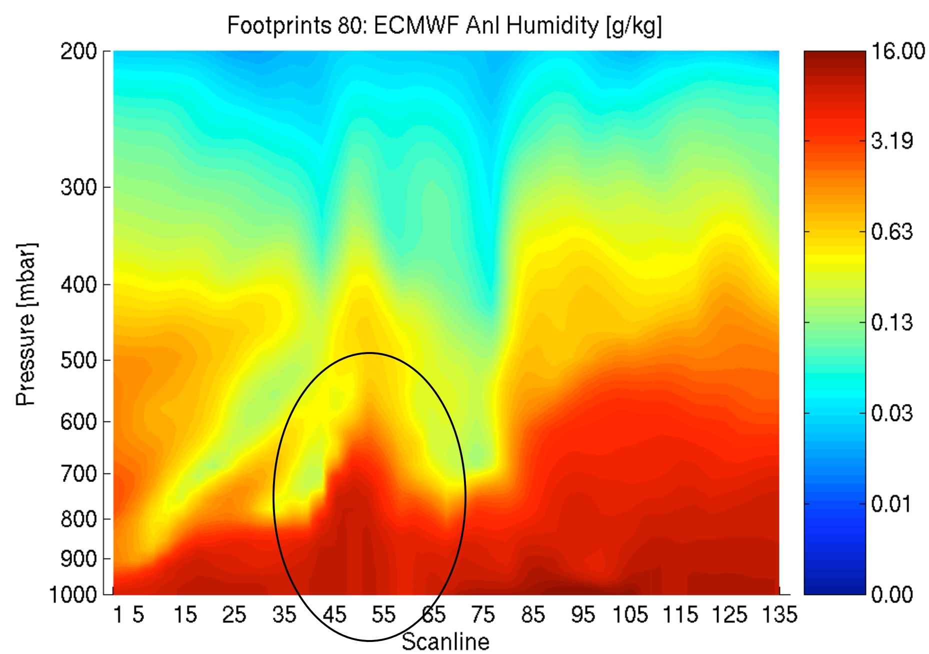
Retrieved Humidity along Footprints 80



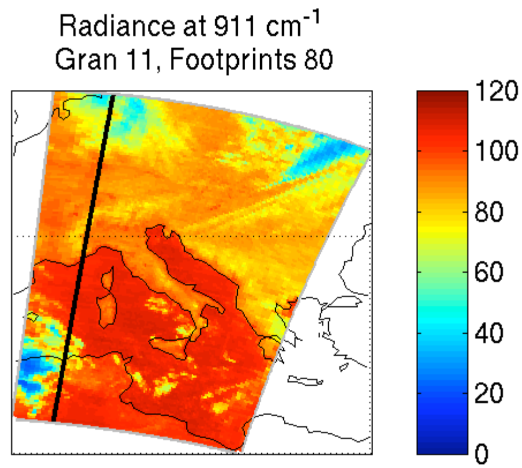
Cloudy RTV



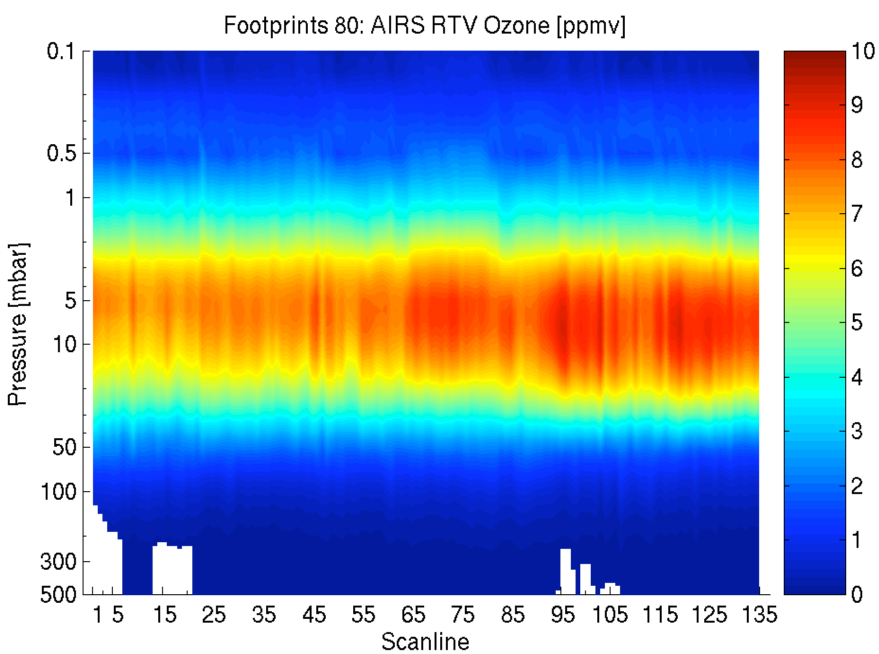
ECMWF



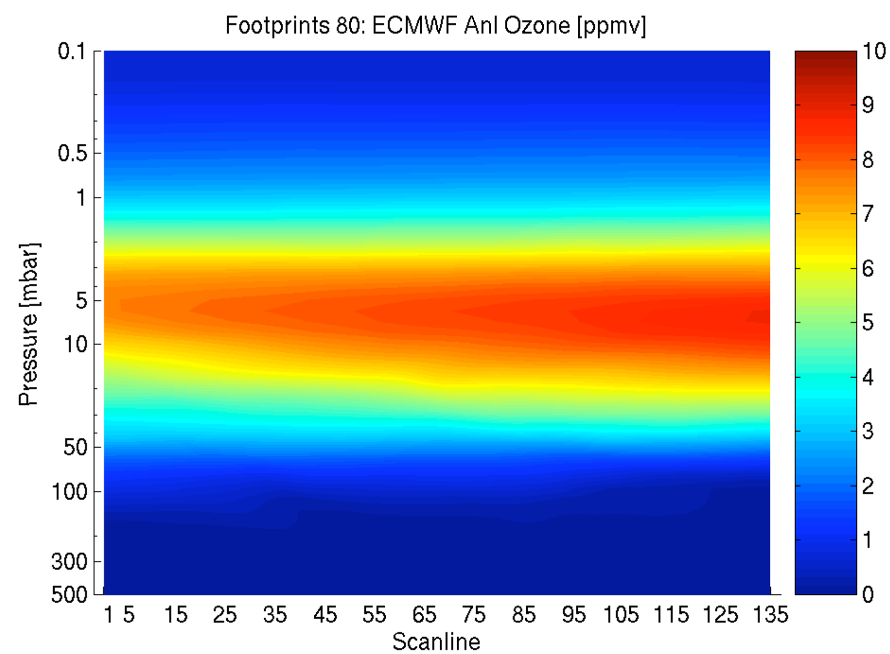
Retrieved Ozone along Footprints 80

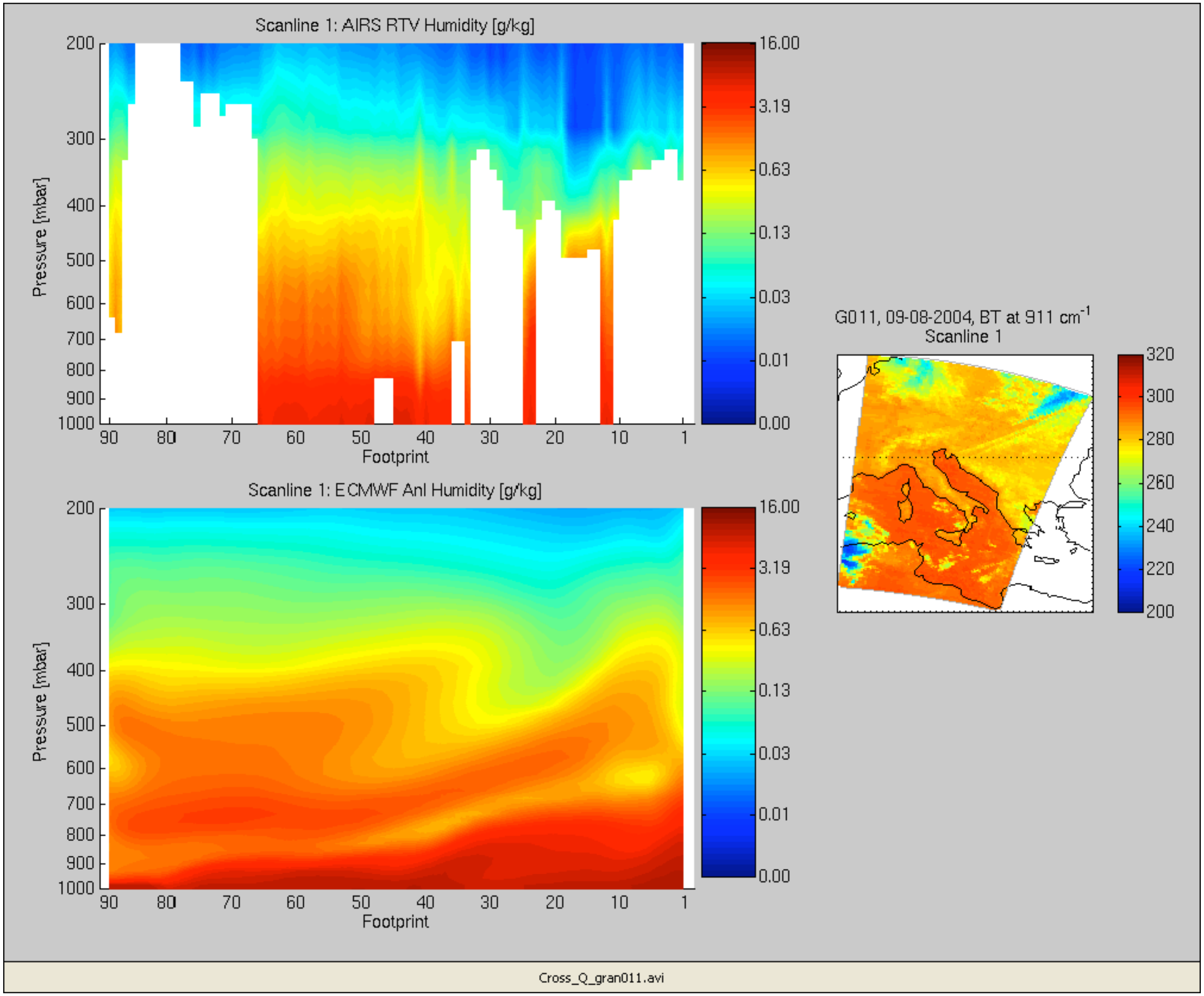


Cloudy RTV



ECMWF



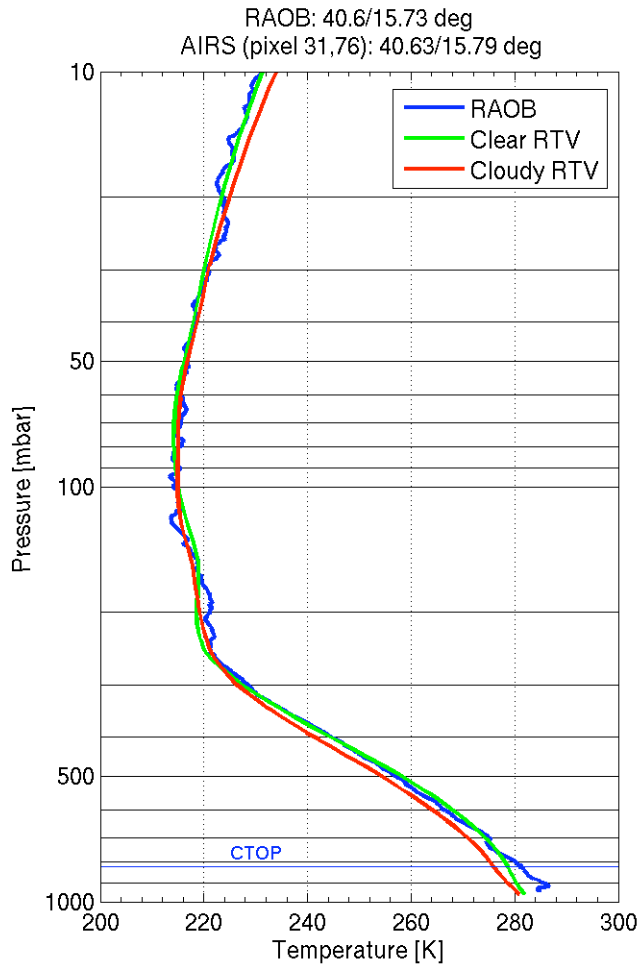


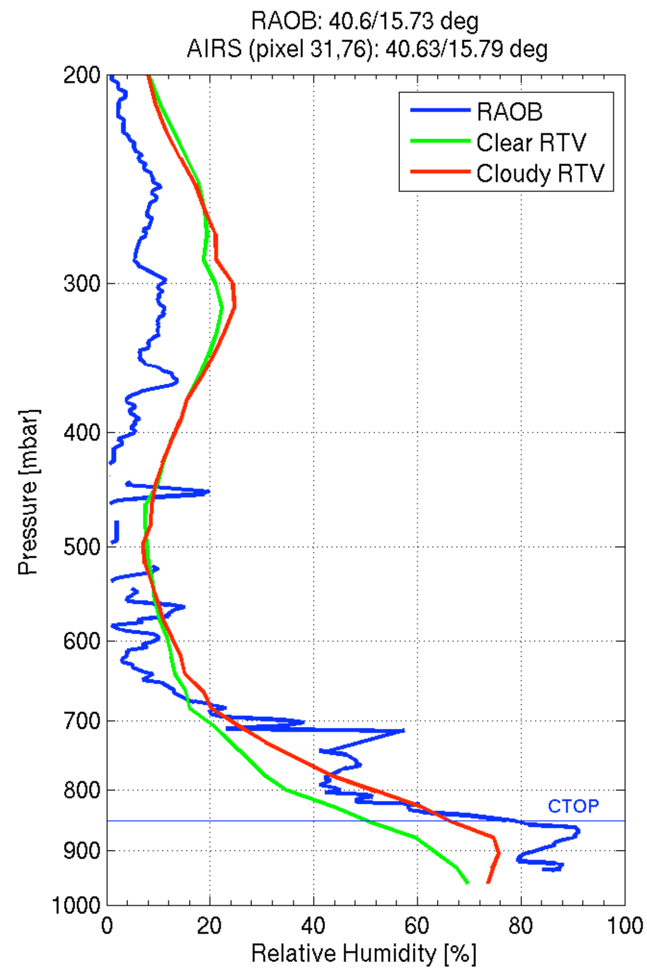
AIRS SFOV water vapor mixing ratio retrievals

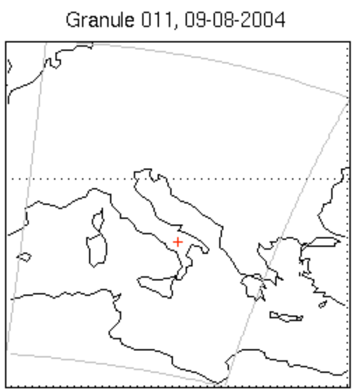
ECMWF water vapor mixing ratio analysis

Comparison with Radiosonde Measurement

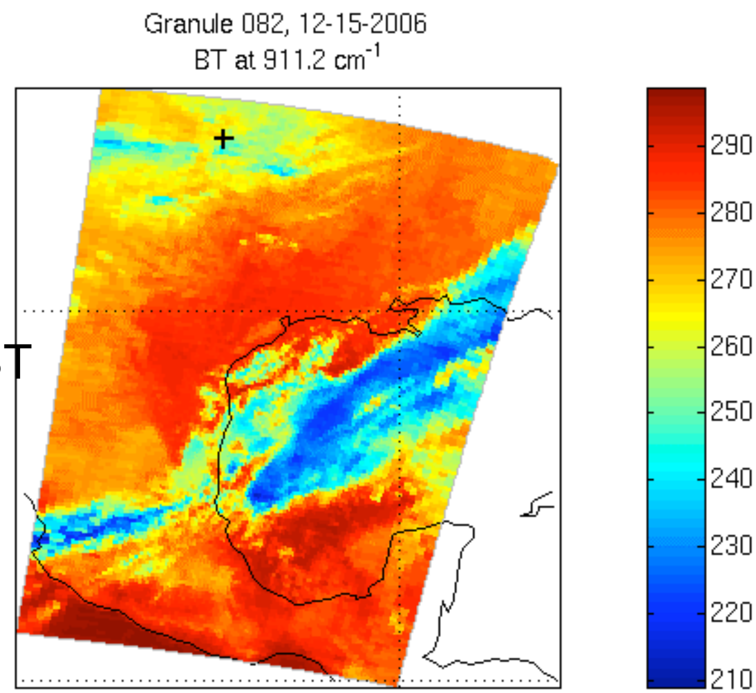
RAOB meas time is 01:40 UTC; Nearest AIRS pixel (footprint 31, scanline 76) meas time is 01:08:52 UTC; thin cloudy footprint;



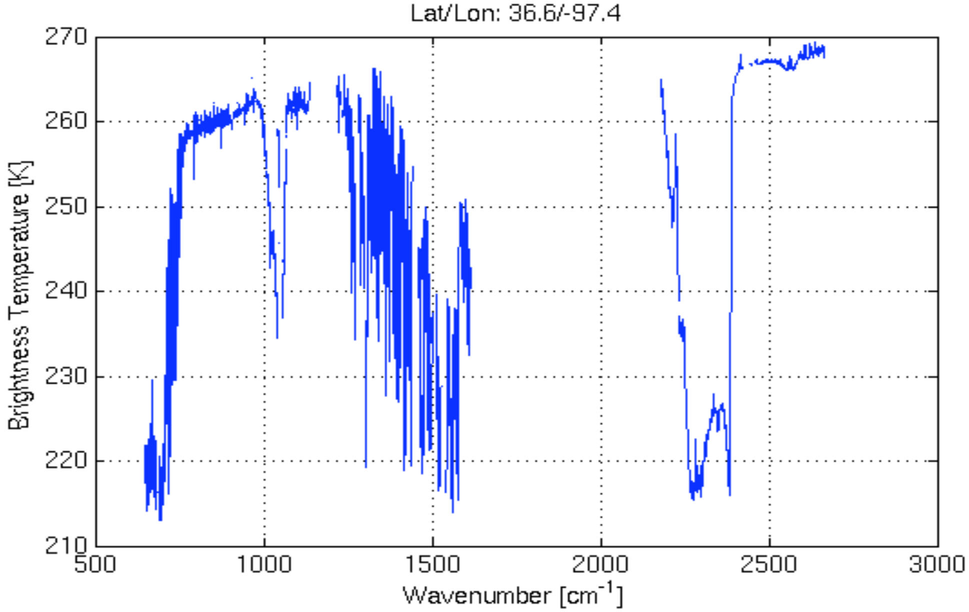


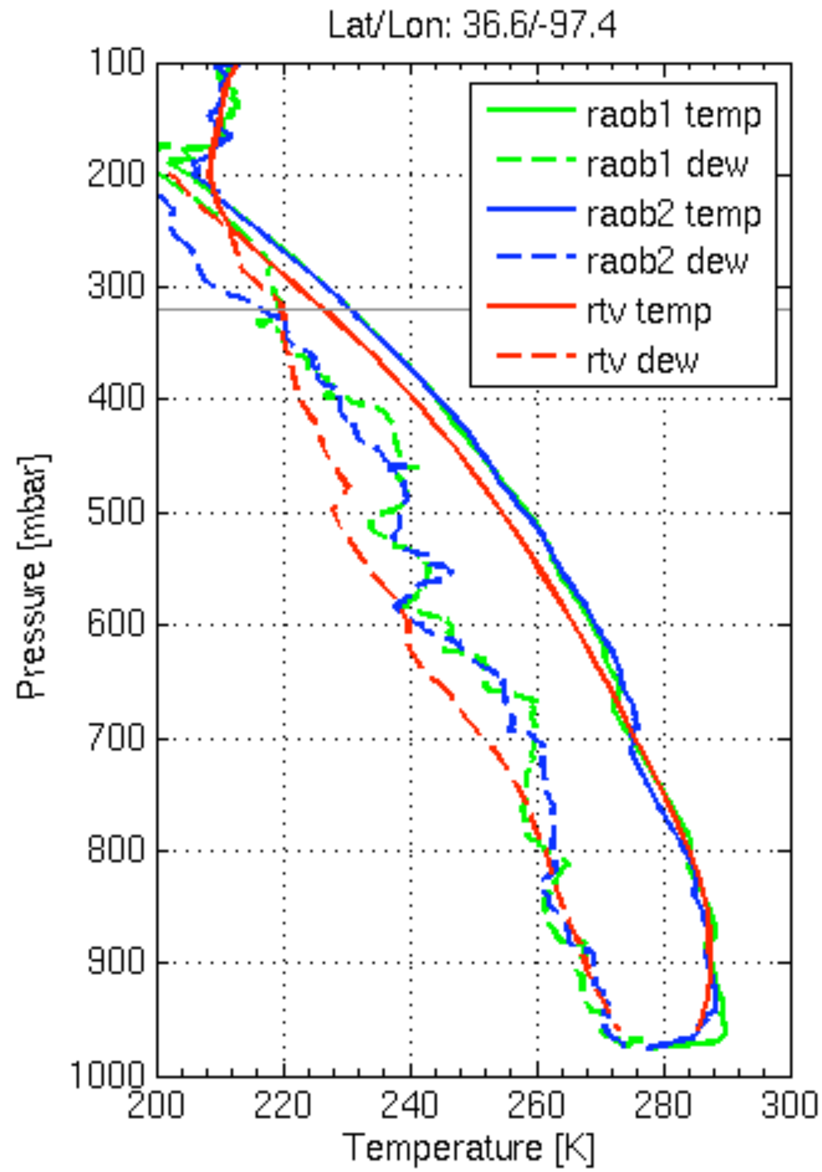


AIRS BT Image



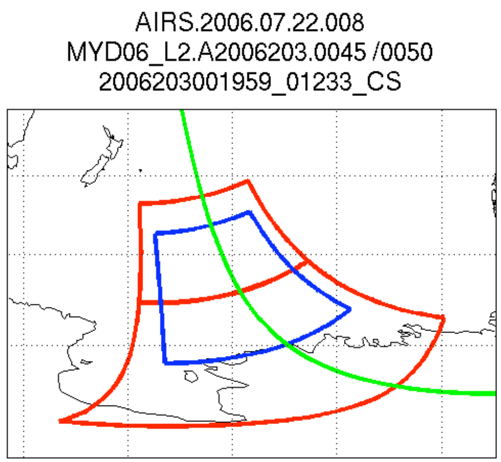
AIRS BT Spectrum at ARM

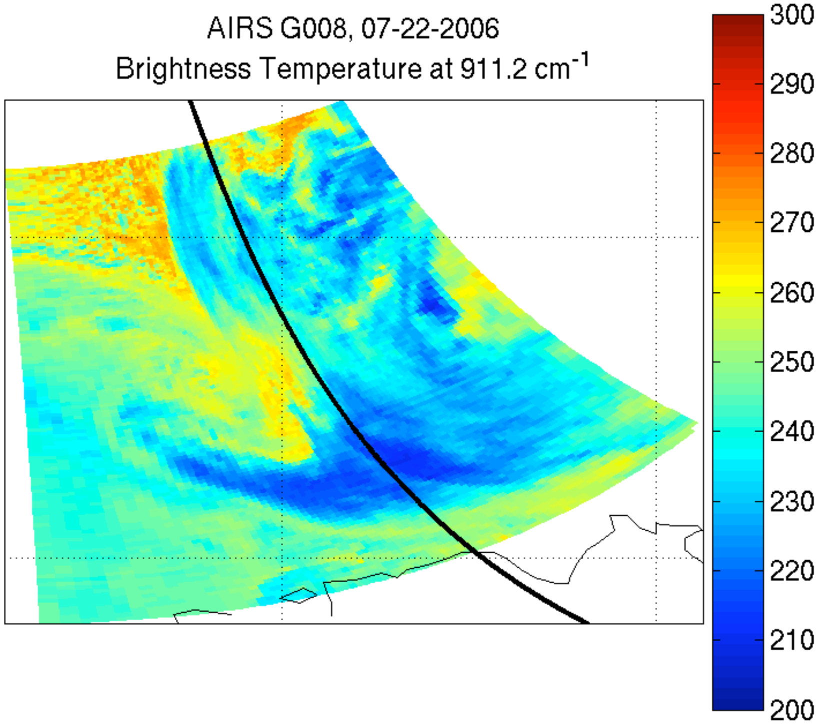


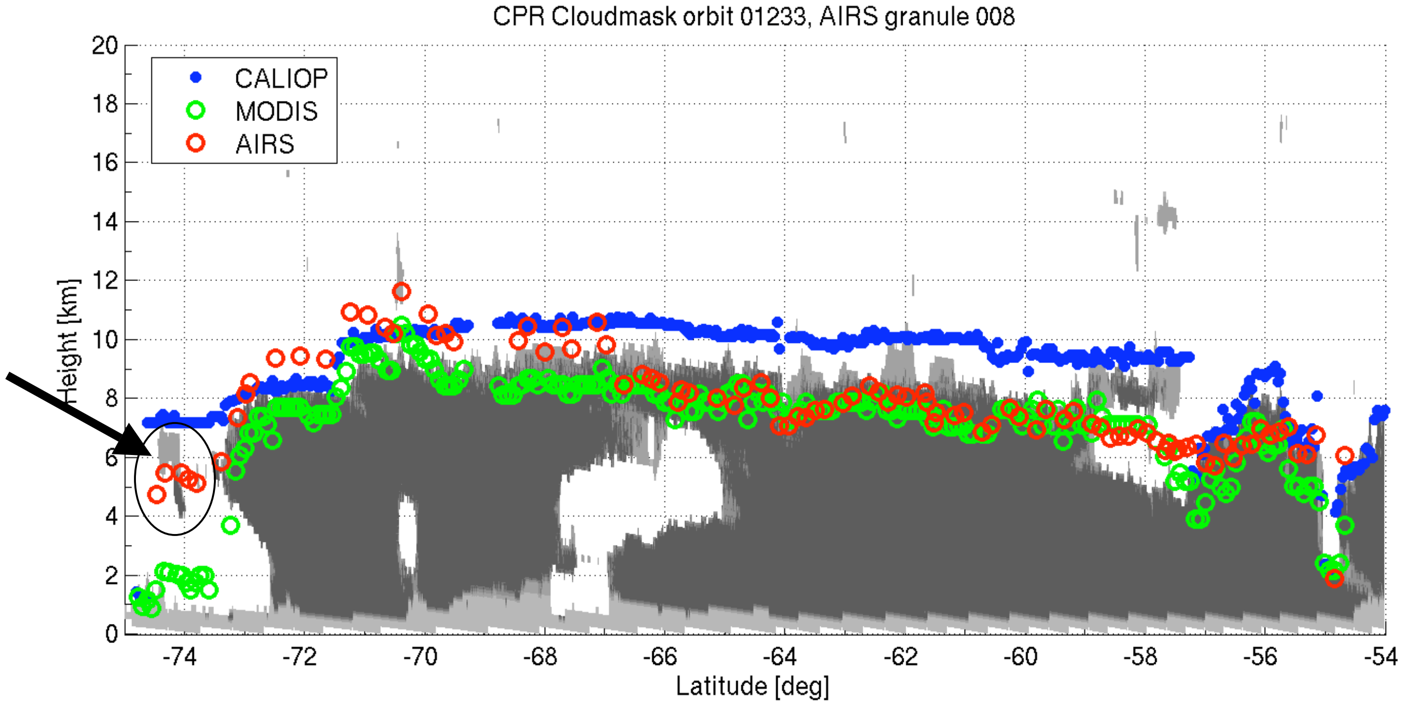


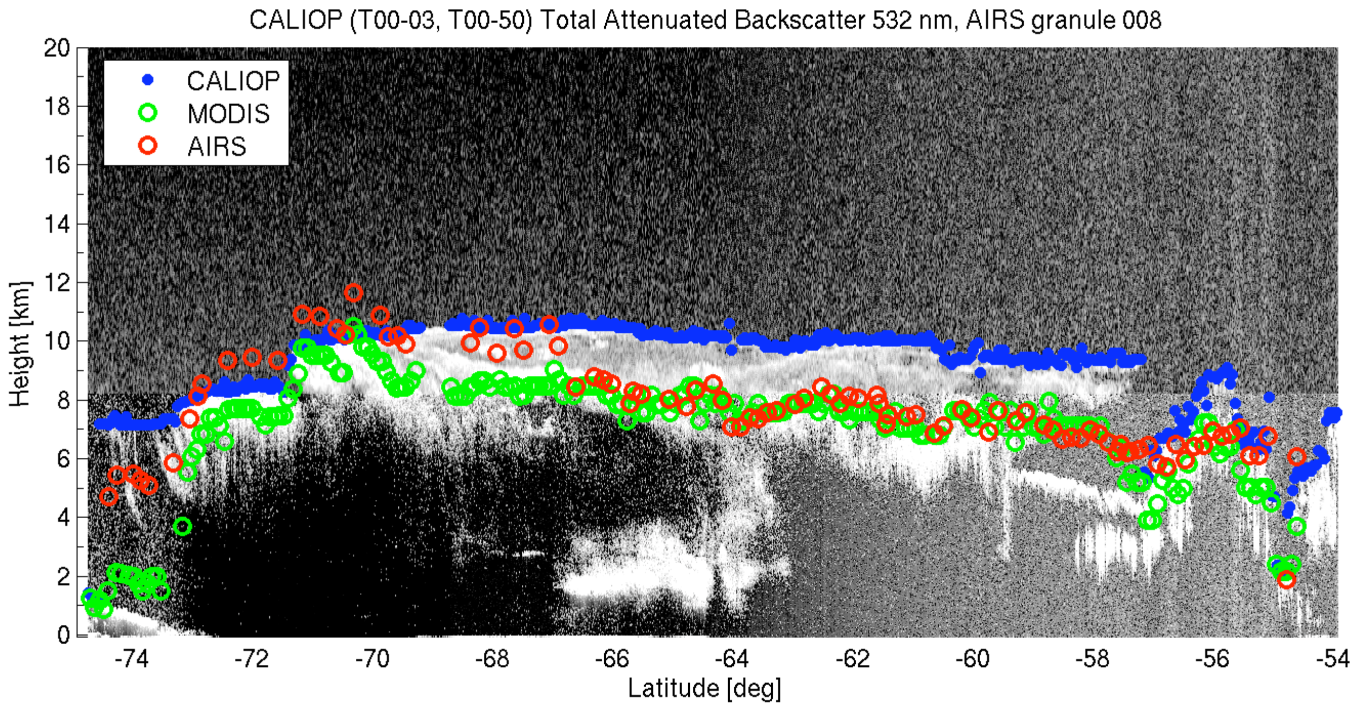
(UW/CIMSS)

Case Study 1: 07-22-2006, AIRS granule 8 (asc)
"Interesting SH 2-layer cloud structure"

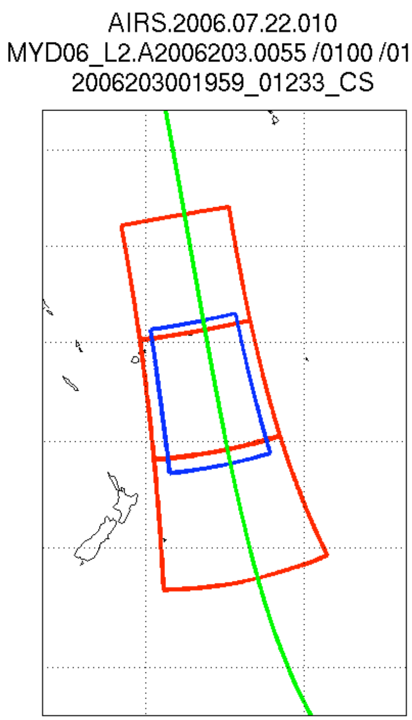


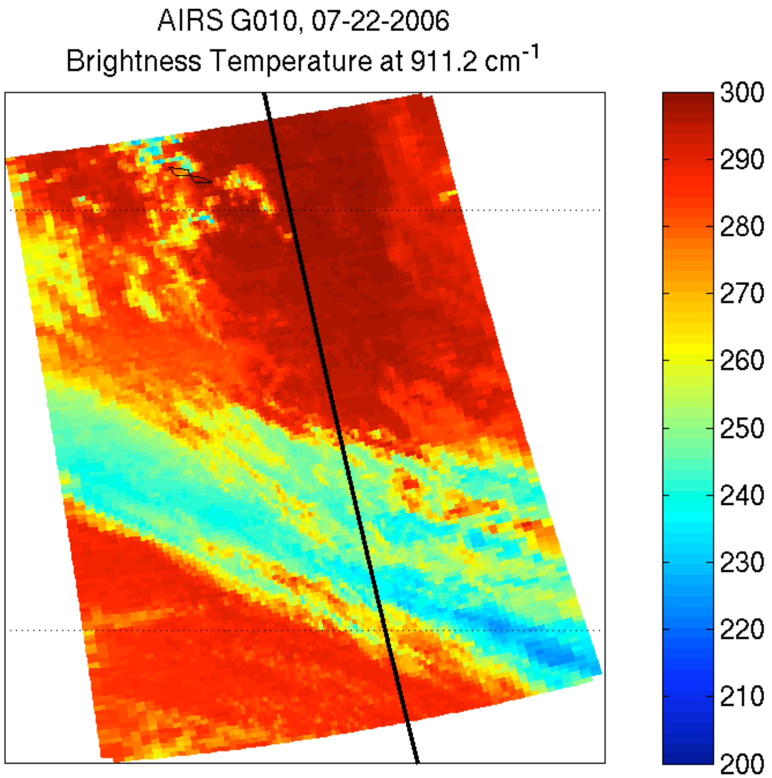



CPR Cloudmask orbit 01233, AIRS granule 008
CALIOP
MODIS
AIRS
Height [km]
Latitude [deg]
20
18
16
14
12
10
8
6
4
2
0
-74
-72
-70
-68
-66
-64
-62
-60
-58
-56
-54

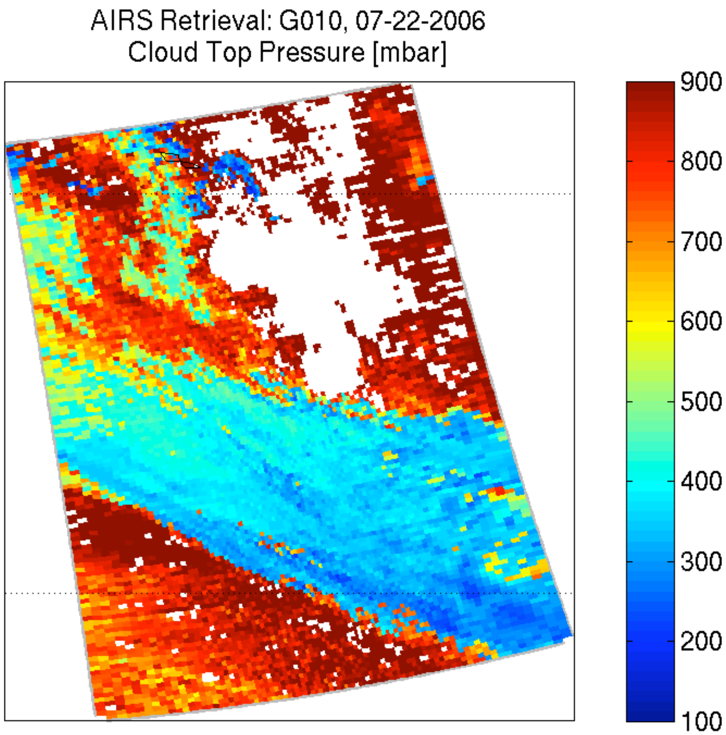

CALIOP (T00-03, T00-50) Total Attenuated Backscatter 532 nm, AIRS granule 008
CALIOP
MODIS
AIRS
Height [km]
Latitude [deg]
20
18
16
14
12
10
8
6
4
2
0
-74
-72
-70
-68
-66
-64
-62
-60
-58
-56
-54

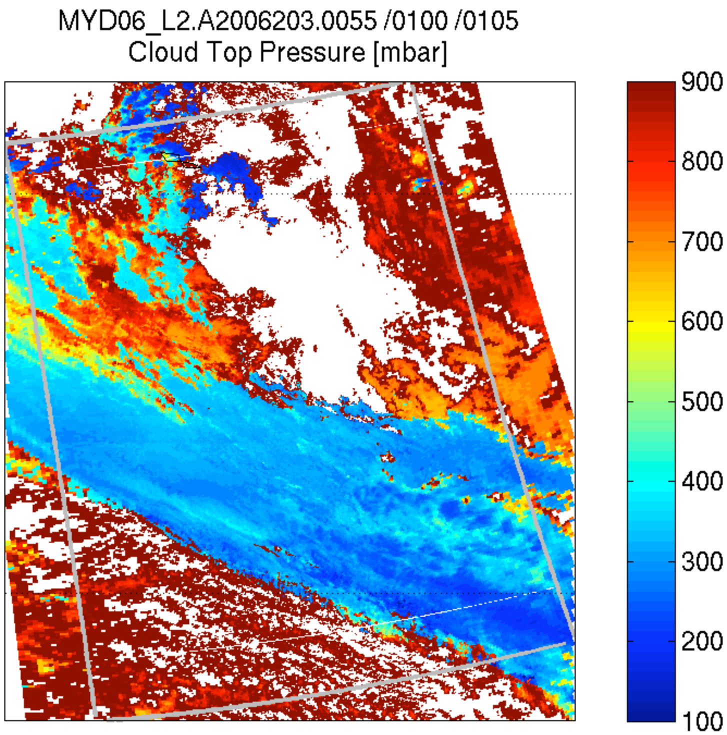
Case Study 2: 07-22-2006, AIRS granule 10 (asc)
"Low-latitude frontal system with some 2-layer structure"

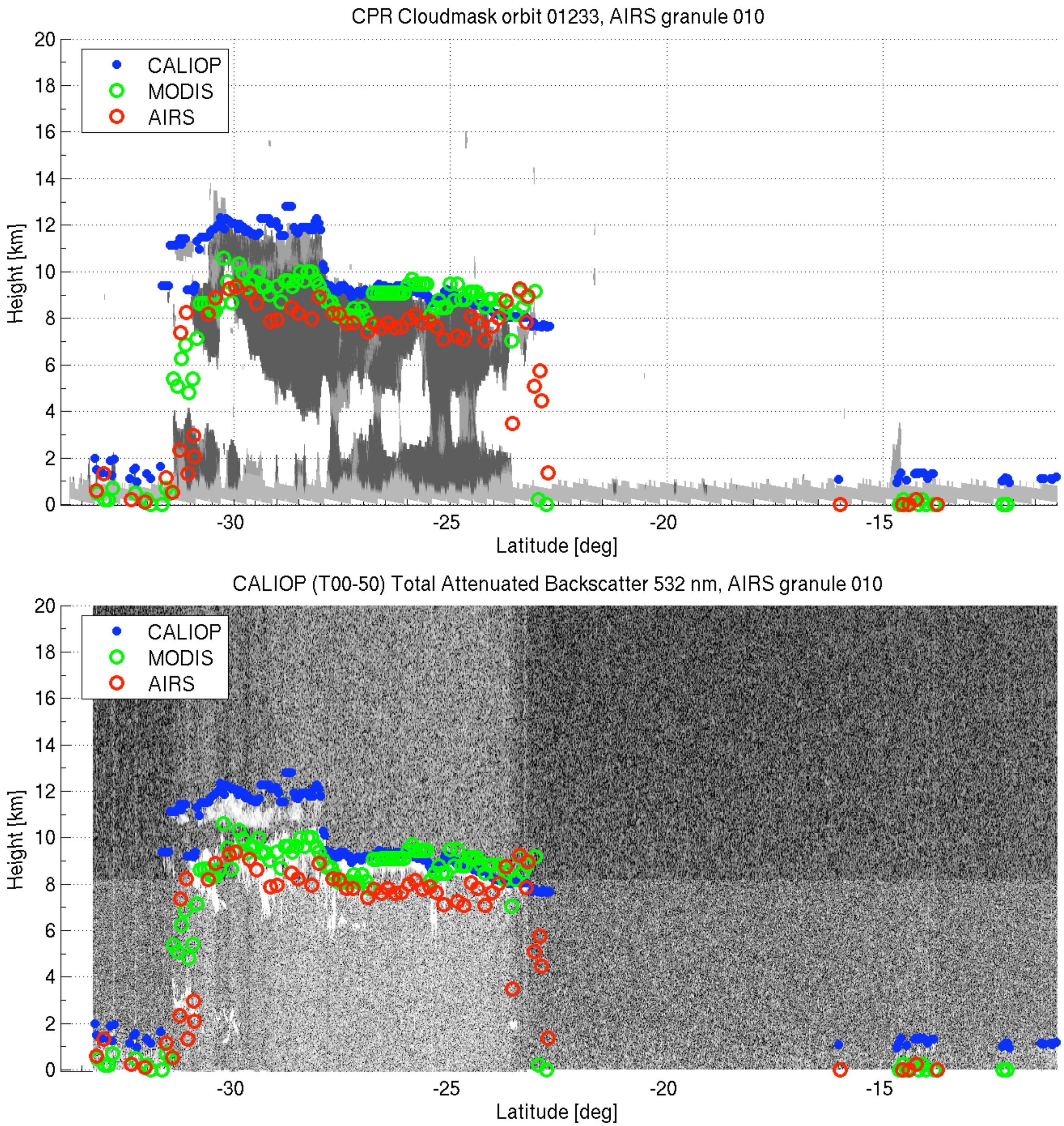




Case Study 4: “Low-latitude frontal system with some 2-layer structure”







CPR Cloudmask orbit 01233, AIRS granule 010
CALIOP
MODIS
AIRS
Height [km]
Latitude [deg]
CALIOP (T00-50) Total Attenuated Backscatter 532 nm, AIRS granule 010
CALIOP
MODIS
AIRS
Height [km]
Latitude [deg]

Summary

- Algorithms for hyperspectral IR alone SFOV approach is developed for retrieval of sounding, surface IR emissivity and cloud property;
- Handling emissivities and clouds in algorithm is very important for in SFOV sounding processing;
- Algorithm has been successfully tested with aircraft based NASTI data;
- AIRS verification shows promising on applying the algorithms to the satellite based hyperspectral infrared radiance processing;
- Algorithm will be further improved and tested with IASI data.